Developing a local deterministic theory to account for quantum mechanical effects

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Abstract

Franson showed that Aspect's experiment to test Bell's inequality did not rule out local realistic theories with delayed determinism. A class of local, deterministic discrete mathematical models with delayed determinism is described that may be consistent with existing experiments. These are not hidden variables theories in the sense that they are not theories of particles plus hidden variables. They are theories of 'hidden' distributed information stored holographic like throughout a space time region. This information cannot be uniquely associated with individual particles although it determines the results observed in particle interactions. The classical parameters of an interaction are determined as *focal points* of continuous nonlinear changes in the wave function and not as discrete events. In addition to not violating Bell's inequality this class of theories can in principle be distinguished from standard quantum mechanics by other experiments. These differences and the experimental constraints on a test of Bell's inequality to discriminate between the existing theory and this class of models are discussed.

Contents

1 Locality

Quantum mechanics is the most accurately verified physical theory in existence. It provides an extraordinarily precise description of all manner of physical phenomena. It is unique among *fundamental* physical theories in providing a statistical description of nature. Many physicists think the statistical description is irreducible. This claim, in contrast to the physical predictions of the theory, is metaphysical. It cannot be verified experimentally or proven analytically. There have been attempts to do so most notably by von Neuman[1] but none of these attempts are accepted as correct today. Bell in his refutation of von Neuman's proof[2] suggested that no such general result is possible. One must impose some additional constraints such as locality to prove anything like this. Bell derived an inequality[3] that no local realistic theory can violate *subject to certain timing constraints*. Bell showed quantum mechanics predicts this inequality is violated within the timing constraints.

There have been many experiments to test Bell's inequality but only one of these, Aspect's[4], have attempted to insure the timing constraints necessary to show a violation of Bell's inequality were met. This is true even of recently reported experiments[5, 6, 7, 8]. A recent proposal to close all loopholes[9] addresses the timing issues but not adequately as we discuss below.

Franson showed that a local realistic theory that possessed what he termed delayed determinism could account for those results[10]. Franson's notion of delayed determinism i. e. that an event may not be determined until some time after it has been completed, may seem strange and unrealistic. However there is no objective definition of event in quantum mechanics. The unobserved microscopic events that Franson discusses (such as the emission of a photon by an excited atom) are hypothetical. It is a mistake to assume that such events occur as macroscopic events do. Quantum mechanics only allows us to compute the probabilities of making observations given certain initial conditions. What happens between the time we set up the initial conditions and make an observation is the *terra incognita* of quantum mechanics. We cannot base the

timing in a test of Bell's inequality on the hypothetical times of hypothetical events.

Franson's objections to Aspect's experiment showed that there is no *objective* criteria in the formalism of the existing theory for computing the timing in an experimental test of Bell's inequality. One way to understand this is through the thought experiment of Schrödinger's cat[12]. Schrödinger begins his description of this experiment with: "One can even set up quite ridiculous cases." A cat is in a superposition of states such that whether the cat is alive or dead is not determined (according to the Copenhagen interpretation) until someone opens the apparatus and observes the cat. An autopsy of the cat would reveal the time of death but the time at which it was *determined* whether the cat lives or dies is when the cat is observed which can be much later than the time of death revealed by the autopsy. I agree this is a ridiculous example, however it is consistent with the formalism of quantum mechanics. There is nothing in that formalism that allows us to know when macroscopic events are irreversibly determined. That question is left to interpretations which for the most part are metaphysical and not subject to experimental tests. Thus there is no way to decide among them. This problem applies not only to tests of Bell's inequality but to any experiment that asks questions about the timing of causal sequences of *macroscopic* events.

If the timing cannot be derived from the formalism of quantum mechanics or from an interpretation of the theory then it must be derived from a competing theory. Developing such alternatives, even if extremely speculative, is a critical element in designing tests of Bell's inequality. The timing constraints I describe in Section 10 apply to a broad class of alternative theories and not just the class of models I advocate. These timing constraints are often assumed by experimenters perhaps without fully realizing that they cannot be derived from the formalism of the exiting theory.

A recent analysis which claims to describe how to close all the loopholes in tests of Bell's inequality[9] is incomplete in its analysis of the timing issues. The authors state on page 3210: "To close this loophole, the analyzer's settings should be changed *after* the correlated pair has left the source." There is no way to know when the pair has left the source unless one detects them at that point which makes the experiment impossible. The speed of the process that generate the photons is only relevant if there is a common trigger for that process and the changing of the polarizer angles. Perhaps this is what the authors are suggesting. The timing can only involve *macroscopic* events such as setting the polarizers or *macroscopic effects* from detecting the photons. The basis for determining the times of these events must come from a competing theory. The authors do not discuss this or the need to base timing on purely macroscopic events. In Section 10 we describe what must be done to address the timing issue in practical experiments.

2 The form of a local realistic deterministic theory

A local realistic deterministic theory will not violate Bell's inequality and will provide a deterministic (not statistical) description of nature. This suggests that it will differ from the existing theory in specific ways. One would expect a local realistic theory to exist entirely in physical space as opposed to the Hilbert space and state space required by the existing theory. Of course it is reasonable to use any mathematics that works as a calculating device. However all physical events occur in physical space and one should reasonably expect a *fundamental* mechanistic physical model that accounts for those events to exist only in physical space.

If probabilities are not irreducible then any violation of locality must violate special relativity. The existing predictions escape this only because the nonlocal effects are 'encrypted' with quantum uncertainty. One cannot tell if an effect goes from A to B or B to A. The predictions are the same in any relativistic frame of reference. However any mechanistic process that produces such results can only be defined in one frame of reference as it must define a unique direction in which the effect travels. The mathematics of quantum mechanics is a mechanistic model and as such must be tied to a particular frame of reference. In non-relativistic quantum mechanics configuration space can only be defined in an absolute frame of reference. In relativistic quantum mechanics there are relativistic fields and a nonlocal state model that is not relativistic. A local realistic theory cannot use higher dimensional state space to produce such irreducibly nonlocal effects without being in direct contradiction with special relativity. Thus is another reason for expecting such a theory to exist entirely in physical space.

Einstein felt that that quantities that were conserved absolutely must have an objective existence beyond the probabilities assigned to them by quantum mechanics[11]. This led Einstein to think that there was some additional information (what other have termed hidden variables) associated with each particle. This information would then explain, for example, both the seeming randomness of observations of a particle's momentum and the absolute conservation of momentum. All attempts at constructing such models (with the exception of Bohm's explicitly nonlocal theory[13]) have been unsuccessful. It seems unlikely that any local model of this type could succeed. This does not exhaust the universe of models. The existing theory may represents the average or statistical behavior of an objectively real physical wave function. Particles may be secondary effects derivable from the wave function and its transformations.

I will now describe a class of models that has these characteristics. I resist calling these hidden variables theories because the hidden information is distributed throughout space as the detailed field values at each point. There are not variables except in the sense that the field value at each point in the discrete

lattice could be considered a variable.

3 Discretizing the wave equation

Near the end of his life Einstein came to suspect that physics cannot be based on continuous structures. He discussed this in a letter to Besso quoted on page 467 by Pais[14].

> I consider it quite possible that physics cannot be based on the field concept, i. e., on continuous structures. In that case *nothing* remains of my entire castle in the air gravitation theory included, [and of] the rest of modern physics.

This insight may be a clue to understanding the nonlinear behavior of a physical wave function. The simplest model for a local deterministic physical theory is a field function i. e. a function defined at each space time coordinate whose evolution is determined by the previous field values in the immediate neighborhood. I think it may be possible to construct all of physics (including particle theory) from a single simple discretized finite difference equation. The starting point for any theory like this must be the classical wave equation for that equation is universal in physics describing both electromagnetic effects and the relativistic quantum wave function (Klein Gordon equation) for the photon.

By 'discretized' I mean an equation that is modified to map integers to integers. A modification is required because there is no finite difference approximation to the wave equation that can do this. The universality of the wave function requires that any discrete model for physics approximates this continuous model to extraordinary accuracy. Discretizing the finite difference equation adds a rich combinatorial structure that has a number of properties that suggest quantum mechanical effects. Perhaps the most obvious is that an initial disturbance cannot spread out or diffuse indefinitely as it does with the continuous equation. It must break up into independent structures that will continue to move apart, i. e., it will eventually become quantized.

We describe how to approximate the wave equation with a discretized finite difference equation. Let P be defined at each point in a 4 dimensional grid. To simplify the expression for P_{xyzt} we will adopt the following conventions. Subscripts will be written relative to P_{xyzt} and will be dropped if they are the same as this point. Thus P_{t-1} is at the same position in the previous time step. $P_{x-1,y-1}$ is at the same time step and z coordinate and one position less on both the x and y axes.

The wave equation is approximated by the difference equation:

$$P_{t+1} - 2P + P_{t-1} = \alpha(P_{x+1} + P_{x-1} + P_{y+1} + P_{y-1} + P_{z+1} + P_{z-1} - 6P) \quad (1)$$

The difference equation discretizes space and time but not the function defined on this discrete manifold. The simplest approach to discretizing the function values is to constrain them to be integers. This requires either that α be an integer or that some rounding scheme be employed that forces the product involving α to be an integer. The former is not possible since it does not allow for solutions that approximate the differential equation.

4 Properties of the discretized wave equation

From the time symmetry one can conclude that any solution must either diverge or loop through a repeated sequence that includes the initial conditions. The restriction to looping or divergence follows from the discreteness (there are a finite number of states) and causality (each new state is completely determined by the 2 (or N depending on the differencing scheme) previous states. The loop must include the initial state because of time symmetry. At any time one can reverse the sequence of the last 2 (or N) states and the entire history will be repeated in reverse. Thus any loop must include the initial conditions.

The time required for a given system to repeat an exact sequence of states based on the number of possibilities easily makes astronomical numbers appear minute. However if there are only a small number of stable structures and the loops do not need to be exact but only produce states close to a stable attractor then we can get a form of structural conservation law.

For large field values this model can approximate the corresponding differential equation to an arbitrarily high precision. As the intensity decreases with an initial perturbation spreading out in space a limit will be reached when this is no longer possible. Thus something like field quantization exists. Eventually the disturbance will break up into separate structures that move apart from each other. Each of these structures must have enough total energy to maintain structural stability. This may require that they individually continue to approximate the differential equation to high accuracy. Such a process is consistent with quantum mechanics in predicting field quantization. It differs from quantum mechanics in limiting the spatial dispersion of the wave function of a single photon. It suggests that the wave function we use in our calculations models both this physical wave function and our ignorance of the exact location of this physical wave function.

5 A unified scalar field

An ambitious goal for this class of models is to unify all the forces and particles in nature using a single scalar field and a simple rule for describing the evolution of that field. The quantum wave function and the electromagnetic field are identical in this model as they are in the Klein Gordon equation for a single

photon and the classical electromagnetic field equation.

All energy is electromagnetic. This requires some way to construct neutral matter from an electromagnetic field. The Klein Gordon equation for a particle with rest mass presents an additional problem.

$$\frac{\partial^2\psi}{\partial t^2} = c^2\nabla^2\psi - \frac{m^2c^2\psi}{\hbar^2} \tag{2}$$

This is the classical wave equation with a new term involving the rest mass of the particle. How can it be derived from the same rule of evolution that approximates the classical wave equation? This may be possible if there is a high carrier frequency near the highest frequencies that can exist in the discrete model. The Schrödinger wave equation for particles with rest mass would represent the average behavior of the physical wave. It would be the equation for a wave that modulates the high frequency carrier. The carrier itself is not a part of any existing model and would not have significant electromagnetic interactions with ordinary matter because of its high frequency.

Such a model may be able to account for the Klein Gordon equation for a particle with rest mass. A high frequency carrier wave will amplify any truncation effect. Because of this the differential equation that describes the carrier envelope is not necessarily the same as the differential equation that describes the carrier. If the carrier is not detectable by ordinary means then we will only see effects from the envelope of the carrier and not the carrier itself. The minimum time step for the envelope may involve integrating over many carrier cycles. If round off error accumulates during this time in a way that is proportional to the modulation wave amplitude then we will get an equation in the form of the Klein Gordon equation.

The particle mass squared factor in the Klein Gordon equation can be interpreted as establishing an amplitude scale. The discretized wave equation may describe the full evolution of the carrier and the modulating wave that is a solution of the Klein Gordon equation. However, since no effects (except mass and gravity) of the high frequency carrier are detectable with current technology, we only see the effects of the modulating wave. No matter how localized the particle may be it still must have a surrounding field that falls off in amplitude as $1/r^2$. It is this surrounding field that embodies the gravitational field.

If discretization is accomplished by truncating the field values this creates a generalized attractive force. It slows the rate at which a structure diffuses relative to a solution of the corresponding differential equation by a marginal amount. Since the gravitational field is a high frequency electromagnetic field it will alternately act to attract and repel any bit of matter which is also an electromagnetic field. Round off error makes the attraction effect slightly greater and the repulsion slightly less than it is in solutions of the continuous differential equation.

Because everything is electromagnetic in this model special relativity falls out directly. If gravity is a perturbation effect of the electromagnetic force as

described it will appear to alter the space time metric and an approximation to general relativity should also be derivable. It is only the metric and not the space time manifold (lattice of discrete points) that is affected by gravity. Thus there is an absolute frame of reference. True singularities will never occur in this class of models. Instead one will expect new structures will appear at the point where the existing theory predicts mass will collapse to a singularity.

6 Symmetry in a fully discrete model

A fully discrete model cannot be completely symmetric as a continuous model can be. There are ways around this like using a random lattice but such models implicitly assume a continuous manifold. In a fully discrete model there must be an absolute frame of reference and preferred directions in that frame related to the graininess of the lattice that defines the space time manifold. One would expect experimental affects from this absolute frame of reference and perhaps such affects have already been observed. It is conceivable that the symmetry breaking that has been observed in weak interactions is a result of our absolute motion against this manifold and not a break down of parity.

7 Dynamically stable structures

It is likely that the structures an initial disturbance breaks into will be somewhat analogous to attractors in chaos theory. These attractors will be dynamically stable structures that pass through similar sequences of states even if they are slightly perturbed. Such structures will be transformed to different structures or 'attractors' if they are perturbed sufficiently. These structures have a form of wave-particle duality. They are extended fields that transform as structural units. It is the 'structural integrity' of these 'attractors' that may explain the multi-particle wave function. These structures can physically overlap. In doing so they loose their individual identities. The relationship between the observation of a particle to earlier observations of particles in a multi-particle system does not require any continuity in the existence of these particles. Particles are not indivisible structures. They are the focal point and mechanism through which the wave function interacts and reveals its presence.

It is plausible to expect such a system will continually be resolving itself into stable structures. Reversibility and absolute time symmetry put constraints on what forms of evolution are possible and what structures can maintain stability. These may be reflected in macroscopic laws like the conservation laws that predict violations of Bell's inequality. Perhaps we get the correlations because there is an enormously complex process of converging to a stable state consistent with these structural conservation laws. It is plausible that at the distances of the existing experiments the most probable way this can be accomplished is

through correlations between observations of the singlet state particles.

In this model *isolated* particles are dynamically stable structures. Multi-particle systems involve the complex dynamics of a nonlinear wave function that at times and over limited volumes approximates the behavior of an isolated particle. Since the existing theory only describes the statistical behavior of this wave function it is of limited use in gaining insight into the detailed behavior of this physical wave function.

Consider a particle that emits two photons. In the existing model there is no event of particle emission. There is a wave function that gives the probability of detecting either photon at any distance from the source. Once one of the photons is detected the other is isolated to a comparatively small region. Prior to detecting either photon there is a large uncertainty in the position of both photons. There is even uncertainty as to whether the particle decay occurred and the photons exist. The existing model gives no idea of what is actually happening. It only allows us to compute the probability that we will make certain observations. Some will argue that nothing is happening except what we observe. In the model I am proposing there is an objective process involving the emission of two photons. There is no instant of photon emission. The photons may start to appear many times and be re-absorbed. At some point the process will become irreversible and the photons in the form of two extended wave function structures will move apart.

An observation of either photon localizes both photons in the existing theory. In my theory there are two localized structures but we do not know the location of these structures until an observation is made. For the most part localization effects do not allow discrimination between my proposal and the standard theory because of the way the existing theory models the localization of entangled particles after an observation. However in an experiment in which a single particle can diffuse over an indefinitely large volume there is a difference in the two theories that is in principle experimentally detectable. Standard quantum mechanics puts no limit on the distance over which simultaneous interference effects from a single particle may be observed. There will be an absolute fixed limit to this in the class of theories I am proposing although I cannot quantify what that limit will be.

Perhaps part of what is so confusing in quantum mechanics is that it combines classical probability where new information allows us to 'collapse' our model of reality in accord with an observation and a physical wave function which determines the probability that there will be a physical nonlinear transformation with a focal point at a given location. The existing theory's failure to discriminate between these two dramatically different kinds of probability may be one reason why it *seems* to defy conventional notions of causality.

Whether a particular transformation can complete depends in part on the conservation laws. Unless there is enough energy to support the new structure and unless symmetry and other constraints are met a transformation may start to occur but never complete. One can expect that such incomplete transfor-

mations happen and reverse themselves far more frequently than do complete transformations. The transformations that continually start and reverse could be a physical realization of Feynman diagrams.

A transformation is a process of *converging to stable state* consistent with the conservation laws. The information that determines the outcome of this process includes not only the averaged or smoothed wave function of the existing theory but also the minute details that result from discretization. This additional hidden information is not necessarily tied to the particles involved or to their wave functions in the existing model. It can be anywhere in the light cone of the transformation process.

8 The conceptual framework of quantum mechanics

It has often been suggested that quantum mechanical experiments produce results that are inconsistent with classical notions of causality. Bell has proven this is true of the mathematics of quantum mechanics but the issue is still an open one with regard to nature. I believe the problem is not with classical ideas of causality or mathematics but with the conceptual framework with which we view experimental results. It is important to deal with this issue explicitly because it is not possible to fully understand the class of models I propose unless one can think about them in an unconventional conceptual framework.

Consider our inability to simultaneously determine a definite position and momentum for a particle. This result is mathematically related to our inability to simultaneously fix a position and frequency for a classical wave. The only wave that has an exact position is an impulse and that is an integral over all frequencies. We do not think that this implies any breakdown in classical notions of causality. The behavior of a classical wave is completely determined just as the behavior of the quantum mechanical wave function is completely determined.

If point like particles do not exist, it makes no more sense to speak of their position than it does to speak of the position of a classical wave. If what we *observe* as position is the focal point of a nonlinear transformation of the wave function then position is a property of this transformation or interaction and not a property of the particle itself. If these transformations result from a process of converging to a stable state consistent with the conservation laws then the information that determines the detailed characteristics of this transformation may be spread out over a substantial region of space and may propagate in ways that are outside of any accepted theory.

Once two particles interact subsequent observations of one particle puts constraints on observations of the other even after the particles and their wave functions have become separated. It is quantum entanglement in the mathematics

of quantum mechanics that is responsible for violations of Bell's inequality and it is the experimental phenomenon of quantum entanglement that makes nature *appear* to be inconsistent with classical causality.

The energy and momentum in a classical wave is distributed throughout the spatial region occupied by the wave. If two classical waves overlap physically there is no clear way to distribute the energy or momentum at a particular point between the two waves. Once the two wave functions for particles in a multi-particle system become entangled how do they become disentangled? The wave function in the existing theory is of limited help if it only represents the average or statistical behavior of the wave function. If observations of the particles involve convergence to a stable state consistent with the conservation laws the the detailed behavior of the physical wave function is dramatically different from and far more complex than its average or statistical behavior in the existing model. Certainly 'disentanglement' will occur if the wave functions of two particles become sufficiently separated. At short distances tests of Bell's inequality will reveal time delays that allow the correlations to be determined by information that propagates locally. At sufficiently great distances the correlations will revert to those consistent with a local hidden variables model. It will appear as if the entangled system collapsed spontaneously into two independent systems. This difference between the existing theory and the class of models I suggest is not limited to Bell's inequality. Perhaps there are experimental tests of quantum entanglement that can more easily be conducted over large distances to discriminate between these alternative theories.

9 Delayed determinism

Because this model breaks most of the symmetries of the linear finite difference equation the classical conservation laws are not enforced at the local level. There can be a small discrepancy at any single point and these discrepancies can accumulate in a statistically predictable way. However discreteness and absolute time symmetry combine to create a new class of conservation laws. The information that enforces them does not exist at any given point in space or time and cannot be determined by a classical space time integral. Instead it is embedded in the *detailed* structure of the state and insures that the same or similar sequence of states will be repeated. The local violations of the conservation laws can never accumulate in a way that would produce irreversible events.

Information throughout the light cone of a transformation puts constraints on what stable states may result. A system may start to converge to two or more stable states but none of these convergences will complete unless one of them is consistent with the conservation laws. The time of the focal point of this process (for example the time when a particle interacts with a detector) and the time when the event is determined, i. e. cannot reverse itself are not

the same thing. Since all interactions are reversible in this model the time when an event completes has no *absolute* meaning. It can only be defined statistically, i. e., the time when the probability that the event will be reversed is less than some limit. Quantum mechanics, because it does not model events objectively, cannot be used to compute the probability that an event will be reversed. We must use classical statistical mechanics. As a practical matter we probably need to limit timings to macroscopic measurements where the probability of the measurement being reversed is negligible. In the model we propose statistically irreversible macroscopic events are determined by large number of reversible microscopic events, i. e. the nonlinear transformations of the wave function. It is important to recognize that use of classical statistical mechanics to define the occurrence of events implies that quantum mechanics is an incomplete theory. It is an assumption consistent with the broad class of theories in which there are *objective microscopic events or processes* that contribute to create macroscopic events.

The distribution of the information that enforces the conservation laws is not modeled by any accepted theory and is not limited by the dispersion of the wave function for the individual particles. This information may be distributed throughout the entire experimental apparatus including both the particle source and the detectors. When quantum entanglement was first discovered there was some thought that it would disappear once the wave function for the entangled particles were spatially separated[15, 16, 17, 18]. Aspect's earlier experiments[19] tested this. These results indicate that quantum entanglement is not limited by the spatial dispersion of the wave function. In a model like the one we are suggesting the linear evolution of the wave function is only part and by far the simplest part of the picture. Information that enforces the conservation laws through quantum entanglement may evolve in ways that are not remotely close to linear wave function evolution. The only reliable measure of nonlocal quantum entanglement is with direct *macroscopic* measurements of time.

10 An effective test of Bell's inequality

Bell's inequality is important because it shows that quantum mechanics predicts macroscopic violations of locality. This can only be tested by suitable *macroscopic* measurements. To discriminate between the class of theories we are proposing one must use statistically irreversible macroscopic events to measure the timing. If the probability of reversal is sufficiently low the events can be treated as if they were absolutely irreversible. If necessary their probability of being reversed can be factored into the experimental analysis. Experimenters often implicitly assume this criteria for the completion of an event even though it cannot be justified in the formalism of quantum mechanics.

Reported experiments generally involve a setup such as that shown in Fig-

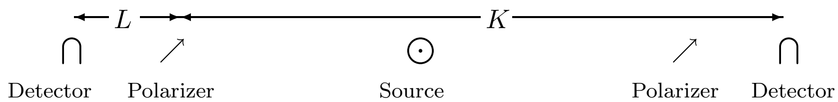

Figure 1: Typical experiment to test Bell's inequality

ure 1. Quantum mechanics predicts that the correlation between joint detection will change as a function of the polarizer (or other experimental apparatus) settings with a delay given by the time it takes light to travel the distance L. Most experiments are symmetric. L is the distance from either polarizer to the *closest* detector. Locality demands that a change large enough to violate Bell's inequality can only happen in the time it would take light to travel the longer distance K. K is the distance from either polarizer to the *more distant* detector. To show locality is violated one must show that the delay (D) between when the polarizer settings are changed and the correlations change is short enough that $K/D > C$ where C is the speed of light.

It is technically difficult to directly measure D and none of the reported experiments do this. Indirect arguments about D are all questionable. We have no idea what is happening between the time the excited state was prepared and the two detections occurred. Thus we can make no assumptions about what is happening microscopically. This is true both because quantum mechanics is silent on what is happening and because these experiments are testing the correctness of quantum mechanics itself.

To directly measure D requires that one have a high rate of singlet state events or a common trigger that controls these events and the change in polarizer angles. If this condition is not met the delay we measure will be dominated by the uncertainty in when a singlet state event occurs. After we change the parameter settings the average delay we observe will be $D + .5C/r$ where r is the rate of singlet state events and D is the delay we want to measure. If $C/r \gg D$ it will be impossible to accurately measure D. Typical experiments involve distances of a few meters. This correspond to expected values of $D \approx 10$ ns. if locality holds and $D < 1$ ns. if quantum mechanics is correct. A high rate of singlet state events or a precise common trigger for singlet state events and changes in polarizer angles is necessary to discriminate between these times.

To show a violation of Bell's inequality one must show the superluminal transmission of information (at least by Shannon's definition of information). One must show that a change in polarizer angles changes the probability of joint detections in less time than it would take light to travel from either detector to the more distant analyzer. For this change to be sufficient to violate Bell's inequality requires that information about *at least one* (we cannot tell which one) polarizer setting influenced the more distant detector. There must be a

macroscopic record to claim information has been transferred. It is the time of that record that must be used in determining if the information transfer was superluminal.

If one can show superluminal information transfer then one has a violation of relativistic locality (ignoring the predeterminism loophole) that is independent of the details of the experiment. Any attempt to enumerate and eliminate all loopholes is insufficient because one can never figure out all the ways that nature might out fox you.

It is worth noting that the historical roots of these predictions is the assumption that the wave function changes *instantaneously* when an observation occurs. This assumption has been built into the mathematics of quantum mechanics in a way that creates irreducibly nonlocal operations. Quantum mechanics insists that there is no hidden mechanistic process that enforces the conservation laws. It is this assumption that creates the singlet state entanglement that enforces conservation laws nonlocally as if by magic with no underlying mechanism.

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